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# U.S. Naval Air Development Center

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Aviation Medical Acceleration Laboratory

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30 December 1963

Psychological Aspects of Water  
Immersion Studies

Bureau of Medicine and Surgery  
Task MR005.13-0005.7 Report No. 7

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**JOHNSVILLE, PENNSYLVANIA**

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**Psychological Aspects of Water  
Immersion Studies**

Bureau of Medicine and Surgery  
Task MR005 13-0005.7      Report No 7

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## SUMMARY AND CONCLUSIONS

The purpose of this paper is to review the recent water immersion literature, placing special emphasis on the psychological aspects of these studies. The adequacy of water immersion as a technique for simulating weightlessness is discussed and its disadvantages are reviewed. The most serious limitation of water in simulation studies was found to be the fact that the body is surrounded by water rather than air. Immersion results in a significant change in the normal physiology and it cannot be ascertained whether the performance and physiological results in water immersion studies would be similar to those in a zero gravity environment. Water immersion facilities and procedures are described and it was found that the wide variation in procedures brings about difficulties in comparing results.

The areas of perceptual and motor performance, boredom and fatigue, sleep, orientation, and personality and emotional aspects of water immersion were selected as being of special psychological interest.

In the area of perceptual and motor performance, a seven-day immersion study demonstrated a gross disruption of psychomotor performance, after the subject came out of the water. Studies of less duration showed no significant decrement in psychomotor performance, except for certain perceptual-motor tasks involving arm movements, where the disruption of the normal kinesthetic feedback was thought to be an important contributing factor. After immersion, several of these studies investigated perceptual-motor performance under centrifugation, but no clear cut conclusions could be drawn concerning the effect of water immersion on G tolerance. It was concluded that much more research needs to be conducted in the area of perceptual-motor performance. Problem areas which were suggested were those of kinesthetic feedback, knowledge of results, interaction effects, reduced mobility, exercise, and the determination of underwater sensory thresholds for pain, pressure, touch, kinesis, and proprioception.

In the area of boredom and fatigue, the studies <sup>also</sup> ~~reviewed~~ demonstrated that boredom is a factor which must be considered in immersion studies, but that subjects were able to tolerate boredom by sleeping or keeping active. Fatigue was found to be detrimental to performance in a seven day immersion study, but in studies of shorter duration, the feeling of fatigue was not a reliable indicator of muscle fitness and did not affect performance. It was felt that the studies in this area have contributed significantly in answering the relevant questions and no new problem areas were discussed.

The results of the sleep studies were found to be ambiguous and contradictory. In a seven-day immersion study the subject required a maximum

of four hours sleep per day, but in a study of shorter duration, the subjects required more sleep than they did normally outside the water, sleeping almost half the time they were in the water and a full eight hours in bed at night. Some critical problems are the amount of sleep that is adequate for an immersed subject and the measurement of the depths of sleep. Improved underwater instrumentation was called for to provide an answer for these problems.

The immersion studies demonstrated a considerable disorientation in the water, especially in the head down and back position. However, in this area the most critical problem is still that of controlling or eliminating the cues that the subject uses to indicate his body position. For that reason, caution must be exercised in interpreting the results of these studies or using the results to provide support for a vestibular theory. These extraneous cues are enumerated and the need for more precise design and instrumentation is emphasized in order to eliminate or control these extraneous variables.

One of the areas of greatest research potential is that of personality and emotional aspects of water immersion. The two studies reviewed demonstrated few individual variations in the form and sequence of mental functioning during immersion. Fantasies, complete boredom, loneliness, and hallucinations of varying intensity and content were experienced by all subjects. Further research is called for to verify the possible enhancement of sensory acuity and of the ability to fix attention brought about by the water. There is a need for a more theoretical orientation by researchers in the area to provide an understanding of the personality dynamics underlying hallucinations and other emotional changes.

## INTRODUCTION

Water immersion has been used as a simulation technique for prolonged weightlessness. The purpose of this paper is to review recent experiments in which this technique has been used. Emphasis will be placed on the psychological aspects which may be involved and on problem areas requiring further study.

One of the fundamental questions in the discussion of water immersion experiments is whether a water environment adequately simulates sub-gravity. For example Knight (1) has argued strongly for the effectiveness of water immersion as a sub-gravity simulator. Other authors, however, in attempting to use this technique, have encountered technical difficulties in applying the principles of water immersion (2, 3, 4, 5, 6, 7). Another important question concerns the effects of water itself on physiological and psychological functioning (2, 4, 8, 9). In view of the relatively large number of recent reports on this topic, together with the absence of specific mention of psychological aspects, a review of the literature, with special emphasis on potential psychological problems, seems needed at this time.

## BACKGROUND FOR WATER IMMERSION

At this point, it would be desirable to define the term "water immersion" as it is used in this paper. In water immersion studies, an environmental system is provided in which water directly surrounds the subject and the subject remains in the water without the protection of an outer shell. These studies attempt to eliminate or control variables such as temperature differences, pressure, and water contact.

Water immersion research may be divided into several categories, such as disorientation, sensory deprivation, physiological alteration, hydrotherapy, and sub-gravity simulation. Although portions of disorientation and sensory deprivation research will be discussed, the greatest emphasis will be placed on sub-gravity simulation research.

In support of water as a simulation technique, Knight (1) has indicated that a body placed in water of uniform, comfortable temperature will not be stimulated by afferent impulses from the exteroceptors and that no skin deformation will occur as long as the entire surface of the body is supported. The sensitivity of the otolith mechanism to differential gravity



stresses is greatly reduced with the head unsupported and the body position supine. According to Graybiel and Clark (6), observers who have experienced both Keplerian flight and water immersion have stated that the feeling of "floating" is similar in the two situations. All of Knight's subjects (1) were impressed with the subjective similarity between the condition of zero-gravity and that of immersion in water.

Water immersion provides only a partial simulation, however, and its disadvantages as a simulation technique are well recognized by experimenters in the field. For example, when the immersed subject moves, the density of the liquid serves to damp movements considerably, requiring much more muscular effort than is necessary in a zero G environment. Respiration is also a problem. The self-contained breathing apparatus limits the time the individual can stay under the water and the subject's freedom of movement is limited by the length of hoses from an outside respiration source. In addition, the human body is not of uniform density and during immersion the body is still acted upon by "field forces" due to the relative densities of different parts of the body. The simulation is further complicated by the fact that the body is surrounded by water rather than by air. Little is known of the reaction of the sensory end organs to such variables as water contact and temperature, thus the effect of water itself on the body might confound the variables that are being measured.

Immersion studies have shown that the water results in a significant alteration in the normal physiology. The cardiovascular system is influenced by immersion (2, 10). In general, the deleterious cardiovascular effects manifest themselves after the subject has come out of the water. As would be expected with reflex mechanisms, Graybiel and Clark (6) and Graveline (10) have reported marked postural hypotension on the tilt table after immersion, as evidenced by a sharp rise in pulse rate, a marked decrease in systolic blood pressure and an abnormal EKG. Beckman, et al's 23-hour immersion subject (2) developed atrial tachycardia beginning at the twenty-second hour and on removal became syncopal upon sitting upright. Beckman, et al reported that the negative pressure breathing situation of immersion to neck level resulted in a change in pattern and an increase in respiratory rate.

The urine and water balance of the body is markedly influenced by water immersion. Graveline and Balke (11) reported a greatly increased excretion of urine, beginning soon after the start of the seven-day immersion and lasting approximately 72 hours. This diuresis was accompanied by a marked loss of sodium during the first two days of immersion. Beckman, et al reported marked diuresis but no unusual electrolyte changes and Graveline

and Jackson (12) reported diuresis, accompanied by increased excretion of sodium, potassium, and creatinine.

The emphasis of this paper is on the psychological aspects of water immersion, not on the physiological aspects, but these physiological alterations are presented to suggest that these crucial changes may well result in important psychological changes in the organism.

## DESCRIPTION OF WATER IMMERSION PROCEDURES

The equipment and specific procedures used in performing water immersion studies vary widely. This diversity can be appreciated from the following description of some of the facilities and procedures used in water immersion studies at various installations.

At the School of Aviation Medicine at Brooks AFB, Texas, Graveline, et al (7) used a small rectangular tank in which the subject, reclining on a web-net couch, with his head supported by a padded headrest, and wearing a "dry" rubber suit, was immersed in water of 33.5° C. to the neck level. Graybiel and Clark (6) at the Navy's School of Aviation Medicine in Pensacola, Florida, used two tanks, 110 in. x 58 in. x 31 in. filled with approximately 742 gallons of physiological saline. The subject's head and neck were supported by a sponge rubber pillow and his shoulders, feet, and buttocks slightly touched a net which was strung 18 in. from the bottom of the tank. The subject wore only a swimming suit. The water temperature was set at 33.3-34.4°C, depending upon the subject's preference. Graveline (13) at the Aerospace Medical Laboratory at Wright-Patterson AFB, Ohio, used a steel tank, 7 ft x 7 ft. x 9 ft. The subject, wearing a "dry" diving suit, was completely immersed in 33° C. water and wore a partial pressure helmet. Beckman, et al's (2) tank at the Aviation Medical Acceleration Laboratory in Johnsville, Pa. was a galvanized iron tank, 5 ft. x 3 ft. x 5 ft. The subject, dressed in a dry rubber suit, was seated in a reclining position in a prototype Mercury contour couch in 34.4° C. water to neck level. Benson, et al (3) also at AMAL, used a circular plastic swimming pool, 28 ft. in diameter, filled with warm water (33.4-35.0° F.) to a depth of 4 ft. The subjects, wearing swimming trunks, were completely immersed and were equipped with diving face masks and underwater breathing regulators, which provided compressed breathing air from outside the tank or from SCUBA underwater diving gear.

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matching lights on the panel so that the subject knew immediately if he had completed the problem successfully

The simple vigilance task consisted of a green light which was turned off by throwing a slide control on the left armrest. The multiple vigilance task consisted of a conventional instrument landing system meter containing a vertical and horizontal needle, which made a cross in the center of the meter under normal conditions. The signals were, up, down, right or left deflections of the needles and the task consisted of operating two levers, mounted on the right armrest, either forward or backward from a spring loaded center position to match the signals. The meter needles returned to the center when the subject threw the correct lever in the proper direction.

The results of the tasks performed during this immersion indicated a significant decrement across days. This performance decrement was indicated by a consistent but small increase in response times on each successive day. The authors stated that this performance decrement during immersion may represent gradual shifts in motivation or increasing boredom and indicated that the task was neither challenging nor stimulating. The observers and the subject were not aware of this decrement during the one-week immersion and had no reason to expect it since few changes in overall effectiveness were observed during immersion. Although the experimenters felt that changing motivational states provided the most adequate explanation for the performance decrement, they did not eliminate the possibility of the water itself as a contributing factor. Systematic metabolic changes throughout the immersion period might be related to performance decrement and the authors called for more research in this area to evaluate this possibility.

In analyzing the complex systems task, the session one week after the immersion was chosen as the most adequate control baseline with which to compare the results of the post-immersion run. The results indicated a significant decrement in the post-immersion run when compared to task performance one week later. The authors indicated that the performance, as observed subjectively in the post-immersion run, was characterized by much more decrement than was shown by the statistical analysis. Observation showed that psychomotor performance was characterized by a marked disorganization of the subject's response pattern, involving a marked impairment in the ability to detect signals and to select and execute responses. Detection was accompanied by an exaggerated startle response to signals having high attention value and

execution was characterized by gross spatial errors. The subject exhibited a gross tremor and an almost stupified appearance. About 15 minutes after post-run performance testing had begun, response movement became more integrated and general improvement was observed in coordination and body control, although gross tremor persisted. At about 25 minutes, scanning behavior became more organized, although control errors (operating the wrong control or using the proper control incorrectly) persisted through the first 35 minutes. At the 35-minute point, the subject demonstrated obvious peevishness and petulance at his errors and shortly thereafter seemed to be overwhelmed by fatigue. Periods of petulance occurred intermittently throughout the remainder of the one-hour session but response integration was maintained. In the last few minutes of the session the subject showed fatigue "blocks" and generalized body twitching. After the session, he reported that he was nauseated, weak, and uncoordinated for the entire hour.

In addition to psychomotor performance tests the subject was tested on a centrifuge in order to study the possible physiological or psychological effects of reentry into the earth's atmosphere from a weightless environment. Before starting the experiment, Graveline had established his control blackout level on the centrifuge and this blackout threshold was unchanged on the post-immersion centrifuge run. Subjectively, however, the G stresses were reported as more severe than pre-immersion runs, producing much more discomfort and marked nausea. In considering these centrifuge results, however, the fact must be noted that there was an 11-hour delay between removal from the water tank and the G tolerance tests. These authors concluded that an astronaut, if subjected to 7 days weightlessness, would encounter major psychomotor decrement during reentry G stress.

Chambers, et al (15) studied the performance proficiency of human subjects before, during, and after immersion in warm water to the neck level for a period of 12 hours. The performance tests, representing a continuum from gross motor to complex perceptual tasks, included tests of target aiming, positioning, steadiness, discrimination reaction time, complex coordination and time estimations ranging from 4 to 240 seconds.

The results indicated that only the target aiming task and the positioning task showed a significant decrement during or after immersion. The target aiming task was presented to test the subject's ability to make precise reaching motions under water. In this underwater task, the subject, with his eyes closed, attempted to mark the bull's eye on a target positioned at arm's length. The results showed that all of the subjects aimed too high.

There were no significant tendencies for lateral error. The positioning task was designed to compare the subject's ability to make positioning movements above and below the water surface. The apparatus consisted of five-push-button switches on each of two panels, one located above and the other below the water. Each button was numbered and the subject responded to verbal commands to locate and depress the appropriate button and the response time was recorded on a clock in the circuit. The results of this task showed that the mean time required to locate and depress the buttons was consistently longer for the underwater condition than for the above water condition.

The interpretation of the failure to find a significant decrement in the other tasks is complicated by the fact that after immersion the task performance could not be measured until the medical examination and physiological tests had been completed. This elapsed time and additional experiences to which the subjects were exposed in taking the physiological measures may have obscured any effects that might otherwise have been observed. The influence of this time delay on the test results was not determined and must await further investigation.

In addition to these psychomotor tasks, a tracking task and a peripheral lights task were presented to each subject as he was being accelerated on a centrifuge. These tests were presented to the subject before water immersion to provide a baseline of performance under acceleration. In this case, the period between exit from the water and the centrifuge runs was greatly shortened with only a half hour delay between the presentation of the tracking and peripheral lights tasks and the removal of the subjects from the water tank. The results of the tracking task indicated no significant difference between pre- and post-immersion performance. For the peripheral light task, the six subjects showed such large individual qualitative differences in their ability to see and respond to the peripheral lights that no clear cut conclusion could be drawn concerning the effect of water immersion on G tolerance, however, six of the seven subjects show some loss of G-tolerance as measured by the peripheral light task.

In a study by Benson, et al (3) twelve professional divers were completely immersed for 18 hours. Before and after immersion; these subjects were run on the centrifuge and their response to positive acceleration was determined by observing the G level at which the subjects were no longer capable of alternating their gaze between two lights 23 degrees to either side of a central visual axis. This terminal condition is known as LOMA (limitation of ocular motility under acceleration). The results indicated a small

but statistically significant decrease in the G level at which LOMA occurred following the immersion period.

In addition to the G tolerance determinations, the subjects were administered a target aiming task and a test of subjective estimation of downward force, prior to, during, and following their period of water immersion. The target aiming task required the blindfolded subject to place small magnets on a target in front of him. The test of subjective estimation of downward force consisted of training the subjects to pull downward on a lever with an estimated force of 15 pounds.

The results of the target aiming task showed a significant tendency for the subjects to place the magnet below the zero-reference point of the target in both the pre- and post-immersion trials, with a greater deviation in the post-immersion trials. While the subjects were completely immersed, they placed the magnets above the zero reference point. This last result agrees with Chambers' study (15) in which all subjects aimed too high on a target aiming task with the arm completely under water. This positive overshoot is due to a well known disturbance of the position sense resulting from the buoyancy of the body when immersed in water and possibly due to a disruption of kinesthetic feedback.

The disruption of kinesthetic feedback under water was emphasized also by the results of the test of subjective estimation of downward force. The subjects exerted a significantly greater force in estimating 15 pounds pull while submerged in water than in either the pre- or post-immersion trials.

Critical Problem Areas. Research by Benson, et al (3) and Chambers, et al (15) have demonstrated the effects of the disruption of kinesthetic feedback on arm positioning tasks under water. Further research should be conducted on the kinesthetic feedback from other body parts and it should be determined if the subject can learn to compensate for a disruption of kinesthetic feedback underwater and improve his performance.

Knowledge of results is an important variable which has not been taken into account previously in underwater perceptual-motor performance results. Thus far no studies have been made in which the subjects have been given any knowledge of their performance while doing the task. It would be interesting to discover to what extent knowledge of results influences performance in the area of positioning tasks.

No research has been conducted on the interaction effects of several variables under water and it is not known to what extent these interaction effects would influence the results. A task variable could be studied in interaction with several variables, such as the temperature and depth of the water, positive or negative pressure breathing, time and order of testing, and knowledge of results.

The areas of reduced mobility and exercise are two crucial areas which have not been studied. The psychological and physiological effects of a subject who is not able to move his extremities in the water are not known at this time. Similarly, no research has been conducted on the effects of a planned program of underwater exercises. The relationship between exercise and performance needs to be worked out. Graveline (10) and Graybiel and Clark (6) have reported feelings of fatigue which are not revealed by the results of performance tests. In view of the discrepancy between objective performance scores and subjective feelings of fatigue, further work is needed to measure the subtle effects of water immersion on highly specific psychomotor skills. When more information is obtained on the specific neuromuscular reactions, quantitative performance tasks may be developed which may measure the subtle impairment of psychomotor skills.

The studies reviewed in this section reflect the emphasis placed on motor performance and the severe lack of research on perceptual aspects. Little has been published concerning the effects on the sense organs of such variables as water temperature and contact. Although thresholds are well known for sense modalities acting in an air environment, nothing is known of the thresholds for such sensations as pain, pressure, touch, kinesthesia and proprioception in the immersion environment. Knowledge of the underwater thresholds for these sensations would be valuable because a decrement in motor performance might be due to the organisms response to these sensory thresholds rather than an actual change in the musculoskeletal system. The primary reason that research on underwater sensory thresholds has not been conducted is the sophistication in instrumentation that is necessary before these thresholds can be accurately obtained under water. However, it is recommended that sensory-perceptual research be conducted to clarify the mechanisms involved in the impairment of psychomotor skills

## **BOREDOM AND FATIGUE**

In Graybiel and Clark's 14-day study (6), the subjects, who were immersed in water for 10 hours a day, adjusted to the routine after the first four or five days and voiced few complaints concerning either the experimental



regime or discomfort. Every attempt was made to avoid the effects of sensory deprivation; thus visitors were permitted, and radio and television were available during their waking hours. After the initial period of adjustment, the principle stress was found to be a psychological one of monotony and the individual differences in coping with this stress were striking. One subject, initially regarded as having the most stable personality, became irritable and had difficulty completing the experiment. This subject remained relatively alert during the daytime, although he desired to escape the monotony by sleeping. Another subject, regarded initially as the least stable, rather enjoyed the experience and was ready to continue indefinitely. He could, apparently at will, spend many hours during the day either asleep or nearly asleep, and this sleep did not interfere in any way with his sleep at night. The most obvious explanation of the differences between these subjects was in their ability to enter a somnolent state or actually fall asleep.

The subjects were given five performance tests: strength of grip, body sway, hand steadiness, leg ergograph, and exercise tolerance on a treadmill. During and after immersion, the subjects showed no significant decrease in muscular strength on any of these tests, however all subjects reported feelings of "weakness" which contrasted sharply with their performance. The authors provided three possible explanations for this discrepancy. First, the change from the recumbent to the upright position on leaving the tank might have resulted in a false sense of weakness; second, the subjects might have interpreted the relaxed state brought about by the relatively high water temperature as general body weakness, and third, the subjects might have been influenced by knowledge of the fact that reduced muscular effort and extended bed rest result in weakness. Graybiel and Clark concluded that the feeling of weakness in immersion studies may be a common complaint, but it is not a reliable indicator of muscular fitness.

In Graveline's study (10) in which he was immersed to neck level for 7 days, a comparison of pre-immersion and post-immersion responses to gradually increased exercise indicated a pronounced decrease in functional adaptability. This was revealed by cardiorespiratory patterns typical of physical fatigue, i.e., higher heart rate, reduced pulse pressure, increased frequency and higher volumes of ventilation. It should be stressed, however, that while the subject was immersed few of the debilitating effects were apparent. Blood pressure, pulse rate, temperature and respiration showed no significant deviations from normal values. It was only upon removal from the water that muscular tone and strength were seriously affected, emphasizing the fact that while the subject is in the water he is unaware of the extent to which muscular debilitation is occurring.

Critical Problem Areas. One of the problems in this area is the extent to which boredom and fatigue are factors influencing the subject's performance. The studies reviewed have provided at least partial answers to this problem but more data is needed for a wider range of conditions and durations of immersion. The studies that were reviewed have demonstrated that boredom is a factor to be considered in analyzing the results of performance in water immersion studies, but it can be tolerated by keeping the subject active or by the subject's own ability to escape from the situation by sleep or semisleep states. No subject has been reported to leave an experiment for the sole reason that he could not tolerate the boredom.

Fatigue appeared to be a problem in that it seriously reduced performance in long term studies of continuous immersion. However, in relatively short studies, the feeling of fatigue was not a reliable indicator of muscle fitness and did not affect performance. In view of the discrepancy between objective performance scores and subjective feelings of fatigue, further work is needed to measure the subtle effects of water immersion on highly specific psychomotor skills. When more information is obtained on the specific neuromuscular effects, quantitative performance tasks should be developed to measure the subtle impairment of psychomotor skills.

## SLEEP

Closely related to the problem of boredom and fatigue is that of sleep. In the seven-day immersion study of Graveline, et al (7) it was concluded that the need for sleep is greatly reduced. Four hours per day were initially allotted for sleep but the subject slept considerably less than four hours and after the second day the range of sleep states became progressively smaller on successive days. In addition, the amount of variability in relative depth or quality of the sleep state showed a progressive reduction across days. The subject spent an average of approximately 120 to 130 minutes in some sort of sleep state each day, however this amount of sleep was entirely adequate for the subject, who remained normally alert at all times during the seven-day immersion and presented no indication of an accumulating sleep deficit.

Graveline explained his findings on sleep by stating that there is no need for the neuromuscular system to counteract continually G-forces in a hypodynamic state. In this environment the neuromuscular "debt" is reduced and consequently the amount of sleep needed to maintain normal efficiency is reduced also. Graveline proposed that "the biological function of sleep is

to provide a period with minimal requirements for counteracting gravity so that recovery from the neuromuscular 'debt' accumulating in man can take place" (7, p. 399).

The results of Graybiel and Clark (6) appear to conflict with those of Graveline, et al (7). Three subjects were immersed 10 hours per day for two weeks. Two of these subjects usually slept over half of the 10-hour period while in the tank. All subjects slept eight to nine hours at night, in spite of rest and sleep during the day.

Graveline and McCally (16) conducted a study in which five subjects, wearing partial pressure helmets and dry type rubber suits, were completely immersed in warm water and were restrained either by a net over the entire body surface or by a tether tied around the waist, allowing the rest of the body to float free. Electroencephalographic (EEG) and electro-oculographic (EOG) recordings were made during 2-1/2 hours of sleep. For the bed rest sleep control recording, the subject, wearing his usual nightclothes, slept on a cot in the same room as the immersion facility, with the EEG and EOG leads attached. The results on depth of sleep were rather inconclusive, demonstrating considerable individual variability in the ability to sleep under water. Three of the five subjects showed a decrement in the ability to sleep when held only by the tether condition and all subjects slept more soundly when they were more completely restrained.

Critical Problem Areas. Much more research needs to be conducted in the area of sleep during water immersion. One of the critical problems that has not yet been answered is the amount of sleep that is adequate for the subject immersed in water. The effects of water immersion on the patterning of sleep is also an important problem area. Other interesting problem areas include the effects of water temperature and depth of sleep requirements.

Improved underwater instrumentation is needed to measure such variables as blood pressure, pulse, respiration, body temperature and brain waves. The measurement of these physiological variables will provide a more objective determination of whether the subject is sleeping and the depths of sleep.

## ORIENTATION

The utricles are generally presumed to signal changes in orientation, by responding to linear acceleration forces. An individual immersed in water thus has some basis for orientation although the usual visual, tactual, and

other cues are absent. Utricular stimulation, elicited by changes in head position, may therefore provide a cue to the position of the body

Knight (1) has reviewed and reported the early work in the area by Stigler and Quix. According to Knight, Stigler (17) in 1912 attempted to measure the orientation of subjects after they had been rotated on a bar while completely submerged. With their eyes and ears covered to eliminate visual and auditory cues, the subjects were instructed to point upward upon termination of rotation. They were seldom able to do this accurately. However the experiment was terminated because the subjects found the experience highly unpleasant and anxiety provoking, and they were unable to hold their breath long enough for adequate observations to be made. Stigler made additional observations with the subjects, equipped with underwater breathing apparatus, stretched out on a board. The board was set in one of several terminal positions and the subjects again attempted to point upward. The subjects were in error by approximately  $15^{\circ}$ .

In 1928 Quix (18) reported a "blind spot" in the utricular sense for subjects in a supine position with the head depressed. Knight, interested in the possible application of Quix's blind spot for providing a better simulation of the null gravity state, repeated Quix's experiment under water. Knight's subjects, equipped with portable high pressure breathing devices, were secured to a tilt table at the bottom of a 7 ft. pool. A protractor on the tilt table measured the degree of angle as the table was moved. The three subjects were instructed to signal when they were certain they had changed from their starting position and to indicate the direction of change. Although Knight reported a large mean threshold of  $17^{\circ}$  he indicated that the clues to the change in position were not due to the vestibular sense, but were due to the crudeness of his apparatus and procedure. Changing pressures for the middle ear and sinuses, bubbles passing over the s. in, changes in water temperature and uneven movement of tilt table all provided additional cues for movement and orientation. Although Knight did not positively identify Quix's blind spot, he did find that thresholds up to  $100^{\circ}$  did occasionally take place with the head orientated in the downward position.

Schock (19) conducted an experiment to determine the perception of the horizontal and vertical on land and in the water for several body positions. The subjects were seated in a tilt chair and were asked to direct the movement of a luminous bar to what they considered to be true horizontal and vertical. The experiment was performed under four conditions: head alone tilted  $45^{\circ}$  left; body tilted  $42^{\circ}$  left, body tilted  $28^{\circ}$  left, and the subject seated erect.

For the experiments in water the subjects wore self-contained underwater breathing apparatus. The results showed that the largest mean total error in establishing the horizontal and vertical occurred in the head alone tilted  $45^\circ$  left, an error of  $6.8^\circ$  in water and  $3.4^\circ$  on land. Tilting the body  $42^\circ$  left also produced an error of  $6.8^\circ$  in water and  $2.8^\circ$  on land. In the erect seated position on land the mean error was only  $1.2^\circ$ , but increased to  $4.1^\circ$  in the water. With the body tilted  $28^\circ$  left, an unexplained anomalous result was obtained in which the total mean error on land ( $4.9^\circ$ ) was greater than in the water ( $3.3^\circ$ ). These results suggest that when the body is upright, postural factors are adequate for judging the horizontal and vertical, but when the body or even the head alone is tilted, there is a pronounced decrease in the effectiveness of judgment. In water, the perception of the horizontal and vertical is further impaired.

Brown (5) performed an experiment to determine the extent of possible disorientation in water when visual, tactual, and buoyancy cues are greatly reduced. Brown asked whether a man at neutral buoyancy in a tank could point to the vertical without making gross head movements, whether he could correct his estimation by head movements, and whether he could orient his entire body to the vertical and swim to the surface.

At a depth of 18 feet, each of the five subjects, wearing an opaque face mask and holding his breath, was rotated by a rod at the rate of approximately one rotation in two seconds. On a signal the subject removed one hand from the rod and attempted to point to the surface. After five seconds the subject tilted his head back slowly, then forward, and made any correction of his first estimate that he felt necessary, then attempted to swim to the surface. The results showed that the greatest deviation from the vertical appeared when the subject made his estimates when his head was in the back or down position through an angle of approximately  $135^\circ$ . Sometimes the error was as great as  $180^\circ$ . This result further substantiated the finding of an increased threshold with the head in the downward position. In all cases, orientation improved after head movements. The magnitude of errors made suggested that the utricles did not provide good static indication of orientation. Thus, when the body was in a fixed position the utricles did not provide an accurate positional sense. However when slight head motions were made with the body in any position, there was a marked improvement in the ability of the subjects to point in the upward direction. Brown also reported that only two of the five subjects appeared to have any difficulty swimming to the surface.

Margaria (20) has reported that the largest errors of estimation of the vertical have been in the head down position. Margaria's subjects were completely immersed, with breathing provided by an underwater breathing apparatus which was carried by an operator to prevent any possible pull on the subject's body. Instead of using a tilt table to position the subject, another operator placed the subject's body in the various positions. The subject estimated the vertical by setting a pointer on a protractor which was fastened to his body. The subjects, as well as being positioned at settings in the pitch axis, were positioned also in the roll axis.

Margaria stated that on the first few trials the subjects appeared to be completely disoriented, with estimation of the vertical made at random. Only after four or five trials did the subjects begin to give reliable results. Margaria indicated that a period of training was necessary for this task. The results of this experiment showed that the best estimations of the vertical in both the pitch and roll axes were made when the head was within  $90^{\circ}$  of its usual upright position.

The most sophisticated and carefully controlled orientation research to date is the study by Diefenbach (21). After a literature review, Diefenbach stated that the differences in experimental findings were due to unaccounted for interactions of several critical factors, such as method of subject support, the subject's method of reporting the vertical, and orientating cues.

Four blindfolded subjects, wearing self-contained air rebreathing units, were rotated in a chair about the pitch axis in a large tank of warm water. The chair was covered with polyester foam to distribute the forces evenly and the subject was wedged into a prestressed state by raising the seat pan toward the fixed head restrainer in order to overcome the variable buoyancy due to breathing. The chair was driven by a 2 hp DC motor which provided a constant low level chair velocity of 3.3 to 3.5 $^{\circ}$ /sec. The subject reported his perception of the vertical by positioning a pointer fastened to the right arm of the chair. The chair angle and the pointer setting readings were made by the underwater safetyman and relayed via microphone to the experimenter on the surface. Twelve positions of body tilt were studied, using  $10^{\circ}$  intervals, starting  $15^{\circ}$  from the vertical. The successive positions were selected at random with the constraints that the subject must be rotated  $120^{\circ}$  between positions and the first, middle, and last positions within each trial must be  $0^{\circ}$  (head upright) to allow evaluation of time and learning effects. The subject's indication of the vertical and the length of time required to reach a decision were taken as dependent variables.

As a control to measure the subject's error in setting the indicator, the subject repeated the trials in which he made the largest error with his blindfold raised and a cork on a string to indicate the actual vertical. Using this information the subject was permitted to reposition the pointer.

The results showed that the subjects made gross errors in estimating the gravitational vertical and that their errors were linearly related to the amount of body tilt, with both average error and variability of error reaching maximum values in an inverted position. The direction of rotation into position and learning did not contribute significantly to the errors made.

A portion of the total error was shown to be due to setting errors, with this error also directly related to body position. Results from the Diefenbach experiment were compared with Margaria's results. Until the Diefenbach results were corrected for the setting errors, the two sets of data showed only a general similarity. However, when the correction was applied, both sets indicated the same pattern, although Diefenbach's experiment revealed larger errors for the angles within approximately  $90^\circ$  on either side of the head-down position. This difference is probably due to the more adequate controls imposed by Diefenbach and the consequent paucity of orienting cues.

Critical Problem Areas. In the study of underwater orientation, the most critical problem area is still that of controlling or eliminating the many cues that the subject may use to indicate the position of his body underwater. This area is an extremely difficult one due to the many extraneous variables that must be controlled. In addition to the vestibular cues, the subject also uses visual cues, change in water temperature, bubbles, middle ear and sinus pressures, limb buoyancy differentials, cues due to apparatus or experimenter error, and possibly others. Some of these cues, such as visual cues and bubbles, are not difficult to eliminate; however, others, such as middle ear and sinus pressures and limb buoyancy differentials, present extremely difficult control problems for the investigator. Before vestibular theory is clarified in the area of underwater orientation, more research needs to be conducted in which extremely precise design and instrumentation is employed to eliminate these extraneous variables.

## PERSONALITY AND EMOTIONAL ASPECTS OF WATER IMMERSION

The possible psychological effects resulting from reduced sensory input, isolation, and confinement in immersion studies would appear to be a profitable area for research. However, few investigators have designed experiments to determine the personality changes resulting from immersion.

In one of the first of such experiments, Lilly (22) submerged a subject completely in a tank of warm water. The subject wore only a blacked-out mask which was fitted with hoses for breathing. After the initial training period, no observer was present. Immediately after coming out of the tank, the subject wrote personal notes on his experience. Since this was a preliminary study, only two subjects were used and the maximum length of exposure was three hours. However, some interesting stages in mental functioning were noted throughout the three hours. During the first hour, thoughts of the day, recent problems, and the environment were predominant. Gradually a state of relaxation, restfulness and enjoyment is experienced. Slowly during the second hour, a need for self stimulation develops and the subject invents hidden methods of self-stimulation such as stroking one finger with another, slow swimming movements, etc. In addition residual stimuli such as the mask and the suspension become focus points for concentration. If this need is satisfied to the extent that it does not force the subject to leave the tank, the subject's thoughts shift from a direct type of thinking to reveries and highly personal and emotional fantasies. If the fantasies are withstood, the subject moves into a stage of visual imagery. After 2-1/2 hours the author reported seeing small, strangely shaped objects with self-luminous borders and a tunnel whose inside "space" seemed to be emitting a blue light.

After the experiment, the subject felt as if he had just arisen from bed and on the night of the day of immersion, he felt that his bed exerted a greater pressure against his body compared with the comfort of floating in water.

Another such study was conducted by Shurley (24). The subject was immersed completely in a tank of slowly flowing warm water (34.5°C). Design of the mask and breathing system allowed effortless breathing without reduction of oxygen tension and without an accumulation of carbon dioxide. Neutral buoyancy of the body was attained by appropriate placement of weights of buoyant, soft plastic material around the mask or body. The mask was full-face and allowed the subject to make comments which were taken down on a tape recorder.

The experimenter and his assistants prepared for the observer role by first using themselves as subjects. The identity and longest immersion times of all subjects were known only to the experimenter. Project personnel were under strict orders not to make any suggestions to the subject concerning what might occur during the immersion.



Twelve subjects of both sexes were used in the experiment. Nine were immersed for periods exceeding 180 minutes but none exceeded 400 minutes.

Shurley presents his findings by including a brief account of the experiences of one subject. He states that this subject was typical. Although there were wide individual variations in specific mental content, there were much fewer variations in the form and sequence of events. The subject reported upon was a 29-year old married male, college trained journalist. Three days before the experimental run the subject was given a three hour familiarization run. In this run the subject experienced headache, stomach cramps, and hallucinated the barking of a dog. However he viewed the total experience as enjoyable and was impressed by the peace and quiet during the immersion and the feeling of unusual calmness and relaxation after the immersion.

As the subject entered the water for the experimental run, he stated that he was determined to use this time to prepare a report and a budget. During the first half-hour the subject was relatively motionless and talked about his everyday thoughts and concerns. In the second hour the subject commented on his increasing urgency for physical activity and expressed a feeling of utter loneliness and solitude. Thoughts of food were dominant in the subject's mind during the second hour and the subject reported sudden intense hunger pangs. The subject reported visual hallucinations consisting in his particular case of brilliant white lights which "looked like the sun streaming through a peep hole" and an inverted "V" in brilliant blue and white flame moving toward him. In the third hour the subject experienced auditory hallucinations, a dog barking and a "crackling sound". Again the subject reported an increasingly strong impulse for physical activity. He exhibited both an elated and then shortly afterward a deeply depressed mood. The subject seemed extremely bored. His thoughts turned to his plan to prepare his budget. Although he reported that he could visualize the complete data sheet in his mind's eye, (an unusual feat for him), he could not concentrate on it. During the last ten minutes he brought himself to the conclusion that he was just wasting time, and although he felt fine, he abruptly left the tank after 4-1/2 hours. Over the entire run, his longest mute period had been less than 6 minutes.

At the post-run interview session, the subject underestimated the duration of his immersion by 25 minutes. At the interview the subject seemed unusually gay and energetic. This unaccustomed energy persisted throughout the day.

The findings in general indicated that mental imagery was present in all subjects for all runs, although the great variety of experience defied classification. Following a run there was a general tendency for pulse, respiratory rate, and blood pressure to drop moderately and for body temperature to rise slightly, although exceptions were noted. Post-exposure feeling states varied both between subjects and for the same subject between runs. Marked calmness and extreme irritability, buoyancy and lethargy, vigilance and somnolence were all observed. Most frequently the investigator observed a mixed state characterized by calm, clear mental vigilance, coupled with lethargy, muscular relaxation and a decided disinclination for exercise, but without any sense or sign of fatigue.

Critical Problem Areas. The area of personality aspects of water immersion has been a neglected area and the few studies that have been conducted have uncovered several interesting problems for additional research.

Electroencephalograms have not been recorded for the subjects reported upon and a more sophisticated physiological recording system could provide interesting data on the relationship between brain waves and reported hallucinations underwater.

It is interesting to note in Shurley's study (24) the extremely clear mental picture of this budget that the subject had. In addition to this, Shurley reported that two physicians who served as subjects independently reported being able to hear their own heart sounds at ear-filling intensity. A third physician reported being able to hear for the first time the gliding sound made by moving his large joints. If these reports are verified by further research, they raise the interesting question of whether water brings about enhanced sensory acuity, lowering of sensory thresholds, or increased ability to fix attention.

Both Lilly (22) and Shurley (24) have reported a great need for sensory stimulation of some kind. Lindsley (23) has suggested that these sensory needs could be compared and quantified by using different forms of very weak stimulation as rewards or reinforcements for the subjects. As the isolation proceeds, it could be determined which sensory stimulus the subject produced first and how much he needed it by how fast he responded to produce the stimulus.

Shurley (24) reported that some degree of imagery was present in all his subjects. A more theoretical orientation by researchers in this area is necessary for the understanding of the personality dynamics underlying these hallucinations.

The psychoanalytic framework is the only personality theory that has been put forth to clarify the dynamics of hallucinations in sensory deprivation. Rapaport (25) has interpreted the hallucinations reported by Shurley as resulting from a sensory deprivation state in which there is a disruption of the dissociation between the id and the ego. The id engulfs the ego, becomes dominant and brings up material previously inaccessible to conscious awareness. This primary process which is generated attempts to remove tension by forming an unreal mental image.

There is a need for additional theoretical explanations for possible effects of water immersion on personality and emotional behavior. The hypothesis generated from these theoretical explanations would then be subject to empirical test through further research. In this light the authors reviewed the personality theories of Freud, Allport, Hebb and Lewin (26, 27) and the theories of Freud and Lewin were found to offer a framework for describing the personality dynamics which may be expressed as hallucinations during water immersion.

Questions of theoretical interest which might be answered through personality theory oriented research include: (1) Are hallucinations the results of some internal stimulus change or are they the result of some external stimulus change (such as sensory deprivation or sensory overload)? (2) Are the hallucinations formed in minute images or in whole-block perceptions? (3) Are there individual differences in susceptibility for hallucinations during exposure to the underwater environment? (4) What role do the body needs play in the possible elicitation of hallucinations? and (5) What other forms of expression of personality and emotional changes occur during water immersion? Although the literature does not stress other expressions, such as fear, anxiety, and aggression, these should be explored. In concluding this section, it should be emphasized that the subjects used in the experiments completed to date were volunteers from relatively select populations, and consequently the data resulting from these experiments cannot be applied yet to man in general.

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